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ABSTRACT

Self-regulated learning with authentic and complex problems requires that learners observe their own learning and use additional information when appropriate (e.g., hypertextual information in computer-supported learning environments). Research indicates that learners in problem-based environments often have difficulties using additional information adequately, and they should be supported. Two studies involving a computer-supported, problem-based learning environment within a medical school analyzed the effect of strategy instruction on the use of additional information and the quality of the problem representation. In study 1, an expert model was used as strategy instruction. Two groups were compared: a group with strategy modeling and a group without. Strategy modeling influenced learners' frequency of looking up hypertextual information but did not influence the quality of their problem representations. This could be explained by difficulties in applying and contextualizing the general hypertext information to the problem. In study 2, the additional information was presented in a more contextualized way as a graphical representation of the case and its relevant concepts. Two groups were compared: a group with strategy instruction text and a group without. Strategy instruction texts supported an adequate use of this graphical information by learners and had an effect on the quality of problem representation. (Contains 29 references.) (Author/SM)

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FOSTERING PROBLEM-ORIENTED LEARNING WITH AUXILIARY HYPERTEXT AND GRAPHICAL INFORMATION

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FOSTERING PROBLEM-ORIENTED LEARNING WITH AUXILIARY HYPERTEXT AND GRAPHICAL INFORMATION

Abstract

Self-regulated learning with authentic and complex problems requires that learners observe their own learning and use additional information when it is appropriate – e.g. hypertextual information in computer-supported learning environments. Research results indicate that learners in problem-based learning environments often have difficulties using additional information adequately, and that they should be supported. Two studies with a computer-suppported problem-based learning environment in the domain of medicine analyzed the effect of strategy instruction on the use of additional information and the quality of the problem representation. In study 1 an expert model was used as strategy instruction. Two groups were compared: a group with strategy modeling and a group without. Strategy modeling influenced learners' frequency of looking up hypertextual information but did not influence the quality of their problem representations. This could be explained by difficulties in applying and contextualizing the general hypertext information to the problem. In study 2 the additional information was presented in a more contextualized way as graphical representation of the case and its relevant concepts. Two groups were compared: a group with strategy instruction text and a group without. Strategy instruction texts supported an adequate use of this graphical information by learners and had an effect on the quality of problem representation. These findings are discussed with respect to the design of additional help systems in problem-based learning environments.

The Use of Additional Information in Problem-based Learning Environments

Theoretical Background

With the constructivist turn in instructional research and the view of learning as an active, constructive and highly situated process, problem-based learning has recently had a kind of renaissance (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990; Cognition and Technology Group at Vanderbilt, 1992, 1993; Collins, Brown, & Newman, 1989; Resnick, 1987). The main idea of problem-based learning is that knowledge acquired in the context of meaningful and authentic problems can more easily be transferred to real-life situations than knowledge acquired in an abstract and systematic way. Of course, the idea of teaching applicable knowledge through problem-based learning has a long history: For example, at the end of the 19th and at the beginning of the 20th century, the 'Reformpädagogik' (reform pedagogy) designed and implemented instructional models which resemble the constructivist view of learning and teaching (e.g. Gaudig, 1922; Kerschensteiner, 1912; see Mandl, Gruber, & Renkl, 1996). Furthermore, the concepts of 'discovery learning' (Bruner, 1961) and 'case-based learning' (see Williams, 1992) share basic ideas of problem-based learning. Although there are some differences in the definition of problem-based learning, most of the authors stress two characteristics (see Gräsel, 1997):

Complex and authentic problems are used in problem-based learning compared to traditional tasks. This means that problems are presented in a narrative story that comes close to reality. In medicine, for example, students deal with medical cases presented on paper or computer. Furthermore, problems should present a good amount of information that is not necessarily relevant for the solution, because 'problem finding' and selection of

the relevant information is very important for solving realistic problems. Finally, the problems should be relevant and stimulating for the learners – and not for the teachers.

The second main characteristic of problem-based learning is that students solve the problem self-regulated and thereby acquire knowledge. Thus, in problem-based learning environments, learners – to the extent that is possible – work with a minimum amount of external control. Learners therefore have to observe their own learning process and correct themselves. Self-regulated problem-solving hence means that it is crucial to control one's own actions and to use the relevant metacognitive control strategies in problem-based learning environments. Based on the research on metacognition, Collins et al. (1989) describe an adequate use of control strategies in problem-based learning environments: When learners work on the problems, they have to monitor their own learning, i.e. they have to observe and evaluate their own learning processes. As long as no difficulties arise (positive monitoring, see Chi, Bassok, Lewis, Reimann, & Glaser, 1989), the application of further control strategies is not necessary. However, as soon as obstacles, contradictions, or comprehension failures are noticed by the learner (negative monitoring), the application of further control strategies is important. Learners then have to specify the cause of the obstacle or comprehension failure. If the learner considers the cause to be in lacking of competencies, self-regulation is necessary. It may be sufficient to consciously activate prior knowledge and to try for the solution a second time in order to overcome the obstacle. In many cases prior knowledge may not be sufficient, and in these situations a comprehension failure should lead to the use of additional information. In problem-based courses, this might mean the use of texts or certain instructional material (e. g. Cognition and Technology Group at Vanderbilt, 1997) or, of course, the support of the teacher. In computer-based

learning environments a very common way to offer additional information for students is through hypertext systems.

On the one hand, the use of further information in a problem-based learning environment contributes to the repair of comprehension failures during learning. On the other hand, an adequate use of information plays a key role for the acquisition of knowledge and conceptual change. But this form of "impasse-driven learning" only occurs when learners use the additional information appropriately. First, among all the sources learners have to find that information which is actually relevant for the repair of the comprehension failure. In a second step, the information must be applied to the problem. In terms of the psychology of problem solving: The information must be integrated into the problem representation in an adequate way. It can thus be presumed that the appropriate use of the information leads to a problem representation which is more elaborate and of higher quality. Proponents of problem-based learning implicitly assume that learners master this self-regulation. They state that comprehension failures are the starting point for the use of additional information (see Prawat, 1993). To what extent students succeed in self-regulation during the process of problem-based learning, has barely been investigated at this point. In evaluation studies of problem-based university curricula, it has been shown that beginners have difficulties with self-regulation (Albanese & Mitchell, 1993; Dolmans, 1994). For example, in the first semesters, students often choose literature which is only loosely related to the content of the course. For example, they are highly influenced by the availability of the literature or themes of parallel courses. Research on metacognition shows that the adequate use of control strategies is often difficult for learners (e.g. Schneider & Pressley, 1989). Several studies have shown that even experienced and adult learners are not successful in assessing their comprehension or correcting their method of learning

accordingly (Glenberg & Epstein, 1985; Pressley, Snyder, Levin, Murray, & Ghatala, 1987). Finally, in research on learning with technologies it was found that hypertext information in computer-learning programs is rarely used by students. Also, it occurs that information in individual hypertext pages is processed superficially and that learners tend to "jump" from page to page and sometimes get "lost in hyperspace" (Dillon & Gabbard, 1998; Jonassen & Mandl, 1990).

In summary, research indicates that it is somewhat optimistic to assume that learners can control their proceedings adequately in problem-based learning environments. As a consequence, problem-based learning environments should be designed in a way that supports learners in their use of control strategies. Recently, instructional researchers proposed instructional methods to support the use of adequate strategies (Cognition and Technology Group at Vanderbilt, 1997; Collins & Brown, 1988; Collins et al; 1989). One thing these methods have in common is that strategies are taught in a contextualized manner. Research on the training of learning strategies stresses the importance of being familiar with the conditions for the use of the strategies (i.e. Paris, Lipson, & Wixson, 1983; Friedrich & Mandl, 1992). Learners not only receive hints about which strategies they should use; they are also informed about how they should concretely handle the strategies in the context of a specific problem and under which conditions the implementation of the strategies is useful.

In the Cognitive Apprenticeship approach, (Collins et al., 1989) the instructional method of strategy modeling is recommended: An experienced practitioner shows how to proceed adequately when learning with complex and authentic problems. Concerning control strategies, a model of an expert gives insight, how the practitioner deals with obstacles or comprehension failures: This can either take place through the mindful

activation of prior knowledge or the use of additional information. Other instructional models in the context of constructivism use strategy instruction texts as a form of support (Fischer, Gräsel, Kittel, & Mandl, 1997; Stark, Graf, Renkl, Gruber, & Mandl, 1995): The students receive short texts that describe the use of the strategies step by step. Of course, instruction texts are widely used in educational settings for different purposes. However, in the constructivist approaches of problem-based learning they are used more specifically: They invite learners to adequately apply strategies in a given problem-based learning environment and therefore support the contextualized use of strategies.

Findings show that, in general, problem-based learning environments are suited to foster the acquisition of applicable knowledge (e. g. Albanese & Mitchell, 1993; Cognition and Technology Group at Vanderbilt, 1997). Nevertheless, it can be assumed that the effectiveness of problem-based learning can be enhanced by fostering an adequate use of control strategies – especially by fostering the use of additional information.

Studies

General Research Question

We conducted two studies with the following general research questions: (1) To what extent does strategy instruction effect the use of additional information in problem-based learning environments? (2) Is there a correlation between the use of additional information and the quality of the problem representation?

Learning Environment

Both studies were carried out in the domain of medicine where problem-based learning at universities is more common as in other subjects. For a learning environment we used the

multimedia learning system 'PlanAlyzer' (Lyon et al., 1990). The cases presented in the program deal with anemia (the lack of hemoglobin). Learners take on the role of a physician, who should come up with a diagnosis for a case and should initiate the appropriate therapy. In the first step, they receive information on the main complaints of the patient. Then they have access to medical history data. In the next step learners have the opportunity to conduct a physical examination. Finally, they get laboratory findings and can observe a smear from the patient as through a microscope to determine the frequency of the cell types.

Study 1

A central element of successful self-regulated learning in a problem-based learning environment is to check oneself and use additional information when prior knowledge is not sufficient to deal with the problem. In the first study we investigate the effect of strategy modeling on the use of control strategies. Two research questions are pursued:

(1) Can strategy modeling promote the use of control strategies in problem-based learning environments? It can be expected that the strategy modeling leads to a more frequent self-regulation during learning. When comprehension failures and mistakes arise, learners should more often try to use additional information or their prior knowledge to correct them. Accordingly, strategy modeling should lead to less frequently ignoring comprehension failures and obstacles.

(2) Does a correlation exist between the use of control strategies and the quality of the problem representation? It can be presumed that the self-regulation of mistakes – either with additional information or the reapplication of prior knowledge – is positively correlated with the quality of the problem representation. In contrast, a negative correlation

can be expected between ignoring mistakes and a well-elaborated and correct problem representation.

Method

Design. 24 fourth year medical students participated in the study. Only students who had completed all courses concerning the content of anemia were asked to participate. After a pretest – factual knowledge of anemia and solutions of short paper-and-pencil cases – learners were introduced to the PlanAlyzer program. Next, all participants had to solve a baseline case without instructional support. Afterwards, the whole group was divided into two groups who worked with the treatment case under the following conditions: Strategy modeling (n = 12) and control group (n = 12). Finally, learners had to work with a transfer case by themselves. The baseline and the treatment case were very similar (anemia due to iron deficiency), and the transfer case differed concerning the findings, the hypotheses, and the underlying concepts (anemia due to leukemia).

Additional information. The PlanAlyzer contains three hypertextual forms of additional information which were used in study 1: (1) The glossary: The students can call on illustrated texts about several terms in the hypertext system. (2) Diagnostic help: The students are given important hints for the physical examination in form of a short text. (3) Databank blood smear: Learners can request information from a picture data bank, which contains several various smears in order to compare them with the one of the patient.

Strategy modeling. Learners in the treatment group were exposed to an expert model who articulated her reasoning while diagnosing a case of the PlanAlyzer; additionally learners saw how the expert dealt with the case on the computer screen (e. g. which kind of information the expert asked for). The expert explained how she advanced in her diagnosis of anemia. For example, she articulated what symptoms she looks for, or how she

interprets the symptoms in reference to differential diagnoses. She also showed how she corrected her comprehension failures and obstacles. Concerning the use of control strategies, she emphasized that every comprehension failure should be tackled and not ignored. She also demonstrated that, for correcting, either one's own knowledge or additional information can be called upon. Subjects in the control group worked on the same case without instructional support; time on task was equal in both groups (60 minutes).

Assessment of the use of control strategies. In many studies, strategies are assessed by questionnaires after learning. Yet, this kind of reflective self-evaluation has some methodological problems (e.g. biases in self-assessment). Therefore, we decided to measure the use of control strategies during the learning process. Learners were asked to think aloud while working on the cases. Think-aloud protocols of the transfer case were analyzed with regard to the strategy use. In the first step, all text sequences that indicated evaluation of one's own proceedings were highlighted. The following forms of control strategies were distinguished: (1) The use of additional information: The students notice a comprehension failure, accept that the mistake stems from a lack in their own knowledge and correct it by using the help systems (e. g. "Pica – I never heard that. I better look it up."). (2) Applying prior knowledge: A mistake can be repaired in the sense that the students attempt to correct the problem through the mindful activation of prior knowledge (e. g. "I have to remember the last lecture about anemia – I guess we had a similar case there. Let me think about that..."). (3) Ignoring: A problem is noticed, but no attempt towards correction takes place (e. g. "I do not understand that the smear looks quite normal. Anyway, I go on."). (4) Positive monitoring: Supplementary, the sequences were coded, in which the students remark that they have learned or understood something (e. g. "I think I' m doing much better than before.").

Quality of problem representation. Before students gave the final diagnosis at the end of a case, they were asked to summarize the case and to illustrate how they came to their diagnosis and ruled out other hypotheses. This oral summary of the case was analyzed with regard to relevant medical concepts. In this analysis, pathophysiological concepts, clinical findings and differential diagnoses were taken into account. The quality of the problem representation was assessed with the number of reasonable concepts.

The degree of use of the control strategies, as well as the quality of the problem representation, were obtained from the analysis of verbal data. Since interval scale data level can not be assumed, we used Mann-Whitney-U-test for the comparison of the groups; for the testing of the correlation, we used Spearman's correlation coefficient. An alpha level of .05 was used for all statistical tests.

Results

Research Question one: Effect of Strategy Modeling on the Use of Control Strategies.

Before the treatment, there were no differences between the two groups: They were comparable both in prior knowledge and in their use of control strategies in the baseline case. After they received the strategy instruction, there were differences between the groups (Table 1): Learners in the group with the strategy modeling used the additional information to correct their comprehension failures more frequently. Moreover, they applied prior knowledge more often to correct their comprehension failures. Finally, the expected difference regarding the ignoring of obstacles could be found: Learners in the control group ignored mistakes more frequently than learners in the group with strategy modeling. Regarding positive monitoring, no differences were found between the groups.

Table 1 approximately here

Research Question two: Correlation between the Use of Control Strategies and the Quality of Problem Representation. Table 2 shows that the expected correlation did not appear. Neither the frequency in the use of additional information nor the application of prior knowledge correlated with the quality of problem representation.
Moreover, data do not confirm that the amount of ignored comprehension failures correlates negatively with a good problem representation. Additional analyses show that strategy modeling had no effect on the quality of problem representation (mean rank strategy modeling (n = 12): 13.13; mean rank control group (n = 12): 11.88; U = 64.5; n. s.).

Table 2 approximately here

Discussion

The results of study 1 show that strategy modeling can influence the frequency of error regulation positively. However, this seems to have no effect on the construction of the problem representation: Neither the use of additional information, nor the application of prior knowledge correlated with the quality of the problem representation. Moreover, the subject's quality of the problem representation in the two groups was comparable.

Concerning the use of additional information, it can be presumed that learners, even with the help of strategy modeling, do not succeed in using the information from hypertexts for the construction of the problem representation. In the strategy modeling group, the

learners were taught that (and how) information from the hypertext system can be applied to the case. It is possible that this form of support is not sufficient for the learners to be able to succeed in applying the general and systematic information to the context of a concrete problem. If the learners do not succeed in contextualizing the information – with or without the use of strategy modeling – then the question arises, whether this form of additional information in problem-based learning environments is really helpful for learners. It is possible that many learners feel over-challenged in applying general text information to problems and in establishing relations between general information and concrete problems. It can be assumed that the additional information should thus have a stronger relation to the problem, especially accenting the relations between concepts and case information. Such a form of additional help was investigated in the second study.

Study 2

In the second study, an information system was developed which avoids the shortcomings of hypertext and supports the learners in the contextualization of the information. The additional information used in this study offers the information graphically. Hence, concepts and especially the relations between concepts are visualized. Like in study 1, the question was whether strategy-instruction has an effect on the use of additional information. In study 2, we focused on the manner in which learners use additional information. We distinguished three forms: adapting, ignoring or declining information. The research questions of study 2 are: (1) Does strategy instruction have an impact on the fact that learners more often adapt additional information, and less often ignore or decline it? (2) Does a positive relationship exist between an adaptive use of information and a high quality

of the problem representation and a negative one between ignoring or declining of additional information and a high quality of the problem representation?

Method

Design. 12 fourth year students participated in study 2. Regarding their learning requirements, subjects are comparable to those in the first study. As in the first study, a prior knowledge test was conducted in the beginning. Afterwards, students were introduced to the use of the PlanAlyzer software. After a baseline case without strategy instruction, learners worked on two cases under two experimental conditions. In the experimental group, learners were provided with graphical information and strategy instruction; the control group received the graphical information without strategy instruction.

Additional information. Additional information was offered to the learners in the form of graphics (a type of concept map) that contained information on the case (symptoms) as well as possible diagnoses. Additionally, the concepts included in the graphical information could be looked up in a hypertext system. In four steps of the diagnostic procedure, the learners were automatically shown the graphical information: the main complaints, the medical history, the physical examination, and the findings in the laboratory. Moreover, students had access to the graphics of the current stage. With each step, the graphics contained more information– suitable to the corresponding step in the program (Figure 1 shows as an example the graphical information after the laboratory tests). In both groups, subjects were provided with a mapping tool with which they could visualize their own solution of the case. The students mapping tool used the same symbol system as the expert maps did (Fischer, 1998; Jonassen, Beissner, & Yacci, 1993). This allowed the subjects to compare the graphical information with their own solution.

Figure 1 approximately here

Strategy instruction texts. For strategy instruction, the learners were given short texts. In these texts it was explained how to use the graphical information for learning, and why it is wise to use it. It was especially suggested that learners compare the expert solution with their own solution, and that they check for own mistakes and correct them.

Assessing the use of the graphical information. Learners were asked to think aloud while they worked with the graphical information. Think-aloud protocols were analyzed regarding the way learners used the graphical information. If the subjects discovered a difference between their solution and the graphical information and thereafter corrected their interpretation appropriately (verbally or by changing their map), an adapting use was coded (e. g. "I didn't think of this hypothesis. I'll change my map if that's possible."). Ignoring was coded, if the difference between the correct interpretation and one's own solution was not at all considered in the learners´ further proceeding. Finally, the information could also be declined, meaning that the difference was justified – for example, if the correctness of the graphical information was questioned (e. g. "The expert thinks of anemia due to iron deficiency. I believe he's wrong.").

Quality of problem representation. At the end of the work on the case, learners gave an oral summary of the case, including their diagnosis and differential diagnoses. As in study 1, the quality of the problem representation was assessed as numbers of reasonable concepts in this summary.

Results

Research Question one: Effect of Strategy Instruction on the Use of Additional Information. The group with the strategy instruction differed from the control group in the process of using the graphical information (Table 3): Subjects in this group were more likely to integrate the graphical information into their own solution. As expected, they also ignored the graphical information less frequently. Concerning declining information and positive monitoring, there were no differences between the groups.

Table 3 approximately here

Research Question two: Correlation between the Use of Additional Information and the Quality of Problem Representation. Data are consistent with the assumption that the quality of the problem representation increases when graphical information is adapted. It could also be confirmed that ignoring the additional information tended to correlate negatively with the quality of the problem solution (Table 4).

Table 4 approximately here

Discussion

The strategy instruction in this study lead to changes in how the graphical information was used by the learners: The information was more frequently used for constructing the problem representation and less often ignored. As expected, the quality of the problem representation is positively correlated with adapting information. In contrast, it is negatively connected with ignoring deviations.

The effectiveness of strategy instruction in this study can be explained in the following way: Without support, the learners have problems in using and interpreting the graphical information adequately. Therefore, the information is often ignored or only partly used to solve the own problem. Strategy instruction texts can stimulate the learners to use control strategies, especially to compare their solutions with the graphical information. This leads to a detection of mistakes and comprehension failures, and it has consequences for the quality of the problem representation. The study gives indications that an adaptive use of additional information in problem-based learning environments has an effect on the quality of learning. Because of the small amount of participants, further research on this topic is needed.

General Discussion

The two studies dealt with the question of how additional information can be used in problem-based learning environments. A fundamental idea of problem-based learning is that the learners should be self-regulated and restricted only to a small degree by teachers or instructors. If their prior knowledge does not suffice for solving the problem, they can reach for additional information and use it to correct their comprehension failures and broaden their knowledge. The studies made the assumption that the proponents of problem-based learning might be too optimistic in their view that learners can succeed in this demanding self-regulation.

The results confirm our assumptions: Independent work with authentic and complex problems shows that it cannot be assumed that the additional information in form of hypertext will be used appropriately. Either the participants use this information only to a small extent, or they are not successful in correctly applying the information. The

results of study 1 even lead to a more pessimistic conclusion: It is crucial for the use of additional information in problem-based learning that the abstract information is applied to a concrete case. Our findings lead us to suspect that these processes of contextualizing of information are not mastered by the subjects in the experiment– even if they use additional information. This assumption should nevertheless be investigated in further studies.

If additional information is offered in relation to the current problem, it can be used more effectively. In study 2, learners received no hypertext system for additional help; instead they were given a graphical representation of information relevant to the problem. The graphical format especially stresses the relations of the information to the concrete case. Nevertheless, this form of contextualized information can be used by learners more effectively if they receive additional strategy instruction.

The following consequences can be drawn from the findings of the two studies: Additional information could only be used by the students adequately, when it was presented in a contextualized manner and when students were supported by strategy instruction on how to use the information. This has consequences regarding the design of problem-based, computer-supported learning environments:

(1) One can assume that extensive hypertext systems are not as helpful for learners as they are supposed to be. The designers of learning environments often commit a lot of time and effort towards the development of hypertext systems. The question arises, whether this effort should not better be invested in the development of other forms of information or help systems.

(2) The data of both experiments show that even advanced learners – fourth year medical students – have difficulties in adequately using information without instructional

support. These findings could have consequences for the development of problem-based learning environments: Designers can not rely on the learners recognizing and correcting their mistakes by themselves. Problem-based learning environments should support these metacognitive control strategies through contextualized strategy instruction.

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Key words

Control strategies, hypertext, medical education, problem-based learning, strategy instruction

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Table 1

Comparison of Control Strategies between the two Experimental Groups (mean ranking)

Control strategy	Experimental group: Strategy modeling	Experimental group: Control group	U	p
	Mean ranking	Mean ranking		
Using additional help	15.88	9.13	31.5	< .01
Applying prior knowledge	16.13	8.88	28.5	< .01
Ignoring	9.58	15.42	37.0	< .05
Positive monitoring	13.42	11.58	61.0	n.s.

Note. Strategy instruction (n = 12): control group (n = 12).

Table 2

Correlation between the different forms of control strategies and the quality of the problem representation (N = 24)

Control strategies	Spearman correlation with the quality of the problem representation
Using additional help	-.09
Applying prior knowledge	-.00
Ignoring	.19
Positive Monitoring	.12

Table 3

Comparison of different forms of the use of information between the two experimental groups

Use of information	Experimental group: Graphical help with strategy instruction text	Experimental group: Graphical help only		
	Mean ranking	Mean ranking	U	p
Adapting	8.17	4.83	8.0	< .10
Declining	6.58	6.42	17.5	n.s.
Ignoring	4.08	8.92	3.5	< .01
Positive Monitoring	5.67	7.33	13.0	n.s.

Note. Graphical help with strategy instruction text (n = 6); graphical help only (n = 6).

Table 4

Spearman correlation between the use of information and the quality of problem representation (N = 12)

Use of information	Spearman correlation with the quality of the problem representation
Adapting	.58*
Declining	-.28
Ignoring	-.52*

Figure Captions

Figure 1. Example of a graphical information in Study 2 (after the fourth step "laboratory test" of the PlanAlyzer). Hypotheses as well as relevant findings are visualized with their interrelations.